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ASTROBLEMES ON TRAPP ROCK: STRUCTURAL FEATURES AND DIFFERENCES FROM IMPACT STRUCTURES ON OTHER TARGETS

V. I. Fel'dman, Yu. V. Mironov, V. R. Melikhov, B. A. Ivanov, and A. T. Bazilevskiy

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ASTROBLEMES ON TRAPP ROCK: STRUCTURAL FEATURES AND DIFFERENCES FROM IMPACT STRUCTURES ON OTHER TARGETS

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Study of astroblemes of the Earth and the rocks forming them (impactites) is a branch of geology which has developed rapidly in the last 15 - 20 years. However, essentially all of the work in this area refers to meteorite craters that emerged from impacts on targets represented by crystalline rocks of the Precambrian shields or sedimentary rocks of the Phanerozoic, i.e., formations of acid or average composition in a petrochemical sense. At the same time, the crusts of the terrestrial planets (in any case, where the necessary data are available) in composition belong to basaltoid. Therefore for comparative planetology it is extremely important to search for and study similar structures on Earth. /139****

The closest analogues to basaltoid planetary crusts on Earth are trap fields. Two astroblemes, Lonar in India and Logancha in the USSR have been currently found on them.

The Lonar astrobleme is located in the state of Maharashtra, India (19°58'45" n.l. and 76°34' e.l.) and has been known since 1823 [La Touch, Christie, 1912]. The formation of this structure has been explained in various years by volcanic eruptions, tectonic processes,subsidence phenomena, etc. [Nayak, 1972]. Back in 1896 the similarity of Lonar and Meteor Crater (United States) was noted [Gilber, 1896], but substantiated suggestions for its cosmogenic origin appeared only in the 1960's [Beals et al., 1960; La Fond, Dietz, 1964], while proof of this came even later [Nayak, 1972; Fredriksson et al.,1973a; and others].

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The Lonar meteorite crater is an almost round depression 1830 m in diameter whose bottom is occupied by a small saline lake (plate 10a). There is another depression (diameter 300 m) to the north of it which is severely modified by dams and canals, but which undoubtedly is also a meteorite crater [Fredriksson et al., 1973a, 1979]. The crater is surrounded by a swell about 30 m high and has true depth of 230 -250 m [Fudali et al., 1980] with visible depth 120 - 130 m (from the top of the swell to the surface of the noncompact lake /140 sediment). The roundness index of the craters (ratio of the radius of the inscribed circle to the radius of the described) equals 0.90 and is one of the highest for impact craters of the Earth and Moon. At the same time, the ratio of the crater swell to its diameter is about 0.17 which is noticeably lower than other craters which are comparable in dimensions and are slightly eroded: Roter Kam (Namibia) 0.28,Tenumer (Mauritania) 0.29, Wolf Creek (Australia) 0.30, New Quebec (Canada) 0.37 and Auelul(Mauritania) 0.40.

The rocks of the foundation complex[1] are decane traprocks of Cretaceous - Eocene age [Kieffer et al., 1976] which overlap the Precambrian foundation with a mantle 600 - 700 m thick [Fudali et al.,1980]. The traprock mass is an alternation of blocks of subhorizontal streams (5 - 30 m thick). The basalt streams have a very oscillating degree of weathering (this is partially a weathering crust,terra rossa paleosoil). On the edges of the crater, the crushed basalts (authigenic breccias) form the foundation part of a swell about 25 m high, where they fall at 8 - 10° angles (less often 20°) from the crater (see photo 10 b), although in places there are blocks with steep drops both from the crater and inside it.

Allogenic breccias are known from the core sample of the wells (drilled inside of the crater cavity) [Fudali et al., 1980; Fredriksson et al,1973b], as well as in ejecta (onto the swell and beyond the crater) where their thickness reaches 5 - 7 m. Allogenic breccias within the crater are clump breccias and megabreccias with dimensions of the fragments to several dozen meters, in which

[1]The plan of Masaytis [1977] was adopted in geological separation of the impact formations. The nomenclature of the impactites is from the work [Fel'dman et al., 1982].

the impact signs fluctuate very strongly: from fracturing to sparse and slightly pronounced destruction cones. Only in zones of intensive impact metamorphism is the rock converted into powder with fragments of basalt of centimeter size, where planar elements in the plagioclase are noted (plate 11,a)* and fractures in the pyroxene (see plate 11, b), maskelynite (see plate 11, c,d) and molten rock glass.

Three modifications (in nature of the fragments and their correlations with the cementing mass) are isolated in the breccias of the ejecta beyond the crater: 1) breccias of strong basalts where the fragments dominate greatly over the matrix; 2) breccias of weathered basalts, with fine-fragment matrix exceeding 50% of the volume; 3) mixed type breccias. The distribution of breccias by area indicates the limited mixing of fragments during their ejection from the growing crater. Thus, the breccias of the first type form compact sections with cross-section of 4 - 20 m that are separated by sections of breccias of the second type (8 - 120 m); the role of the mixed breccias is small. Study of the granulometric composition of breccias in the outcrops indicated that the dependence of the frequency of encounter of the fragments on their dimensions (fig. 1) is similar to that previously established for craters Janisjarvi (Karelia) and Kara(Polar Ural) [Basilevsky et al., 1979].

No molten impactites in Lonar are known in any large independent bodies. They are only observed in comparatively small (up to 20 cm maximum) fragments in allogenic breccias and usually have signs of aerodynamic treatment, ridges and grooves with characteristic pattern of rotation in flight.

The gravimetric study of the Lonar astrobleme which was made in 1964 by Kaylasam [Fudali et al., 1980] indicated that a round negative anomaly about 3.6 mgal in size similar in its structure to the changes in the gravitational force field in the Wolf Creek and Tenumer craters which are close in size corresponds to the crater.

*Translator's note: plate 11 is not included.

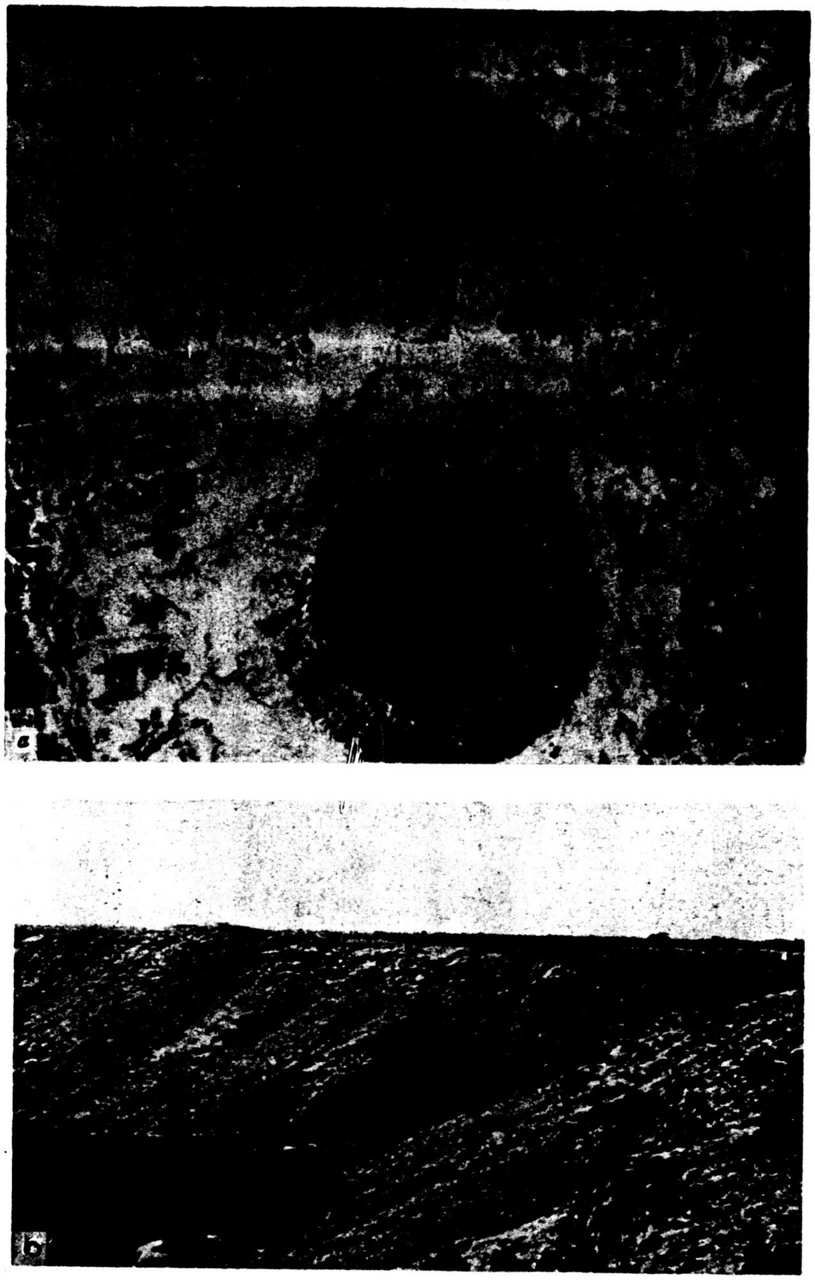

Plate 10. a. Aerial Photograph of Lonar Meteorite Crater [Fredriksson et al., 1973a]; b. Foundation Swell of Crater. Inclination of strata from crater is visible.

The age of the Lonar crater which was determined by two methods is in limits of 50,000 years (track method) to 30,000 years (radiocarbon method) [Fredriksson et al., 1979].

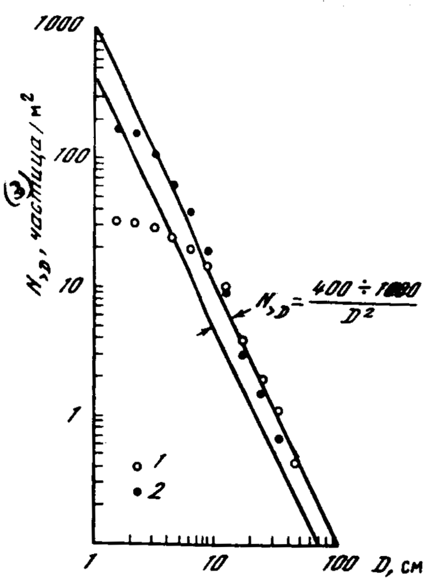

Figure 1. Dependence of Quantity of Fragments (with size greater than the given N > D) on Their Diameter in Allogenic Breccias of Ejecta Beyond the Lonar Crater

Key:

1. breccias of weathered basalts
2. breccias of strong and weathered basalts
3. particle

The Logancha astrobleme is located in the Evenkiy national region (65° 30' n.l. and 95° 50' e.l.) and has been known since the 1950's when it attracted the attention of the geologists by its regular shape and freshness of the crater. At various times its formation has been linked to saline cupola or volcanic processes /141 [Lebedev et al., 1975; and others]. The cosmogenic nature of the Logancha depression was shown in 1982 [Vishnevskiy et al., 1983; Feldmann et al., 1983].

The Logancha annular structure has a well-pronounced round shape and is clearly isolated on space photographs of scale 1:1,000,000 and other space and aerial photographs. In the modern relief, this is a crater about 20 km in diameter and 500 - 550 m deep. The morphological plan (fig. 2) also clearly shows the regular outlines of the structure (outlined by conventional structure contours made every 100 m), modified comparatively slightly by erosion. The bottom of the crater is almost flat, swampy, although it is drained by many small rivulets. The edges of the crater are gently sloping (6 - 7°), have slightly pronounced concave shape. There is no swell; a slight inclination of the surrounding rocks from the crater center is only noticeable from interpreting aerial photographs (S. S. Bobkova, partial report). The Logancha astrobleme is a complex crater with central elevation (fig. 3). The primary diameter of the crater (if the equality of the volumes of the primary crater and the modern depression, and the ratio of depth to diameter for its evaluation is adopted as about 0.25) was probably about 14 km [Feldmann et al., 1983]. Interpretation of the aerial and space photomaterials makes it possible to reveal a large number of fault disorders of varying order, including numerous annular and radial faults which are genetically related to the formation of the astrobleme. Their arrangement, in particular, determines the distinct radial and tangential directions of the Logancha River valley and a number of its tributaries (see fig.2). The central elevation has a cross-section of about 4 km and projects above the bottom of the depression by no more than 50 - 70. It is formed of upper Permian (Degalinskiy series) and lower Triassic (Tutonchanskiy series) rocks and in the western part is covered with a mantle of glacial deposits. The central elevation has a block structure in which the rocks in the blocks several hundred meters in size lie at very different angles, from 30 - 32 to 70 - 80° and azimuths from southwest through west and northwest to east and east-southeast. The blocks are separated by fault disorders of various directions, which usually have a close-vertical incidence.

Rocks of the foundation complex belong to the upper Permian sedimentary carboniferous formations (Degalinskiy series) and lower Triassic volcanogenic and volcanogenic-sedimentary formations (Tutonchanskiy, Korvunchanskiy, Khonnamakitskiy, Nidymskiy and Kochechumskiy series of the traprock mass). The carboniferous mass is formed of aleurolytes with interlayers of carbonaceous and argillaceous shales; the carbonaceous shales upwards through the cross-section become argillaceous shales, and higher, aleurolytes. In the lower part of the cross-section (visible) in some outcrops there is a level of very altered (carbonate, quartz)amygdale-stone basalt porphyrites. The lower Triassic formations of the traprock mass are usually subdivided into tufogenic (two lower series) and lava (three upper series) complexes about 400 - 1000 m thick respectively. The lava complex is generally characterized by rhythmic structure: alternation of lava covers of basalts and tufas of varying dimensionality. The tufas are usually more widely developed in the lower cross-sections of the series, while the lavas are in the upper parts. In the tufogenic part of the cross-section there are also volcanomictic sandstones and aleurolytes. In the traprock complex there are also hypabyssal intrusive formations which are represented by stocks and dikes of microdolerites and dolerites.

Authigenic breccias are widely developed. They include essentially all the outcroppings of preQuaternary rocks among the glacial deposits and in the lower parts of the edges (photoplate 12, a,b).* In this case, the stronger and more uniform intrusive traprocks have slightly pronounced signs of fragmentation as compared to effusive rocks and tufas which are fragmented more strongly and nonuniformly. Allogenic breccias were only recorded in t he upper Logancha river. They are formed of fragments of different basalts up to 10 - 20 cm in size, sometimes by clumps 1 - 1.5 m (less often up to 2 - 3 m). The breccia cement is psammite and is approximately 25% of the composition. Vishnevskiy [Vishnevskiy, Dolgov, 1983] have also noted suevite-like rocks.

The age of the crater is defined from geological data as post-lower Triassic and younger than the Cretaceous - Paleogene peneplain formation (less than 12 - 15 million years), but preIce Age (more ancient than the Zyryanov glaciation, i.e., 120,000 - 125,000 years). Fairly significant erosion apparently shifts the real time for formation of the astrobleme to the Neogene - end of the Paleogene.

The Logancha astrobleme is well pronounced in the magnetic field where it corresponds to a distinct annular anomaly with

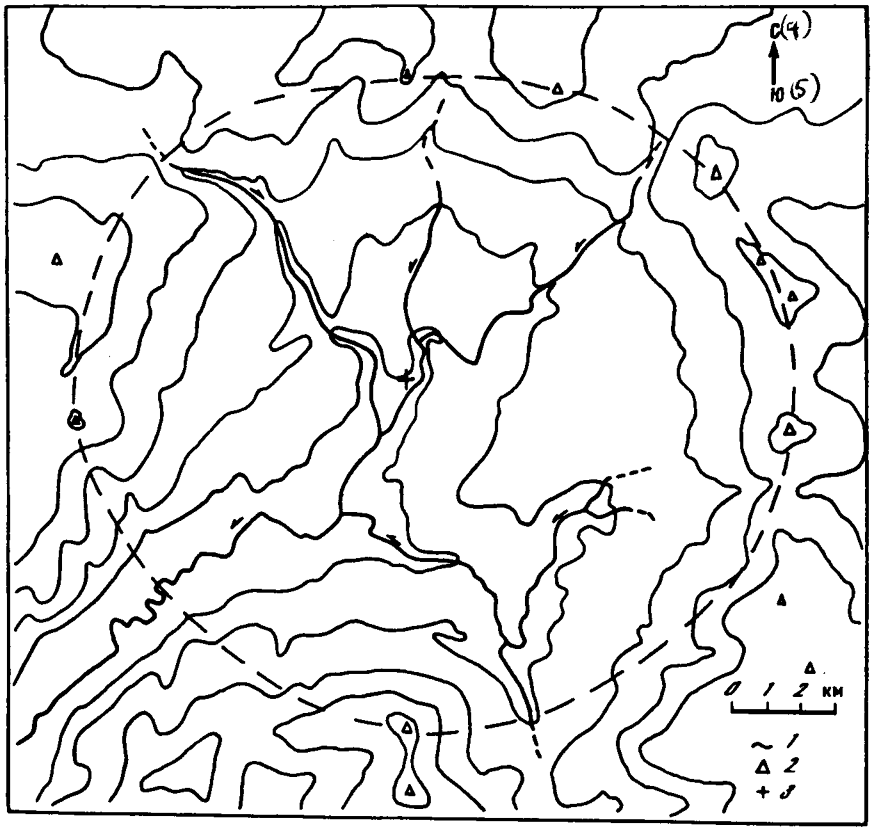

Figure 2. Morphological Plan of the Logancha Astrobleme
Key:

1. Conventional relief levels (cross-section approximately every 100 m)
2. Watershed crests
3. Center of structure
4. North
5. South

reduced values of ΔT_a inside and positive semicircular surrounding anomalies. In the gravitational field, the astrobleme was only recorded after removal of the regional background and local anomalies related to large fault disorders of regional plan. Under /143
these conditions, an annular strictly symmetrical anomaly of zonal structure is revealed with alternation of positive and negative zones. Quantitative modeling makes it possible to hypothesize a section (fig. 4) which corresponds well to a meteorite crater (14 km in diameter) with lens of molten impactites (9 km in diameter) around a central elevation (3 km in diameter) which contains

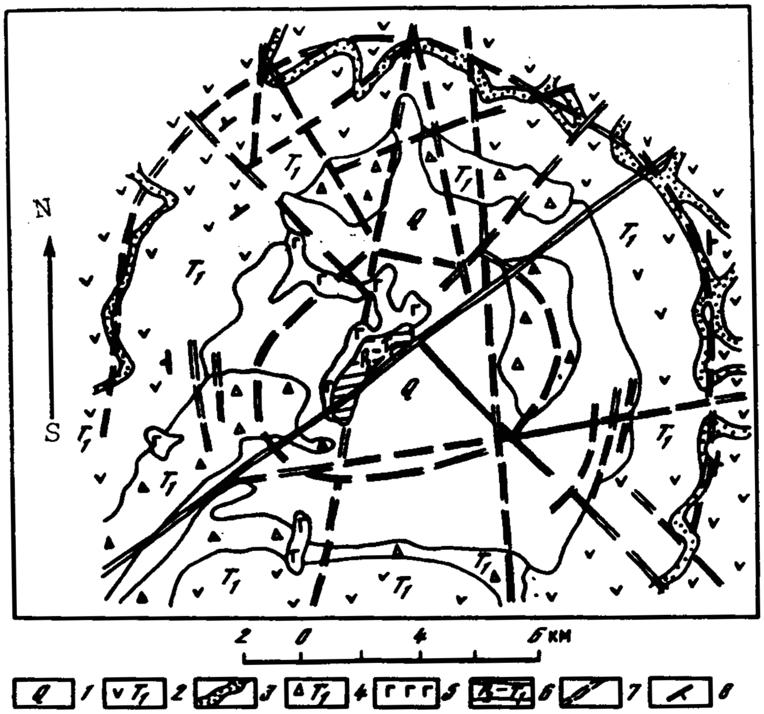

Figure 3. Plan for Geological Structure of Logancha Astrobleme (from data of A. T. Stulov, Z. S. Bobkova et al. with changes)

Key:

1. Upper Quaternary glacial and modern alluvial deposits
2. Volcanogenic and volcanogenic detrital rocks of lower Triassic (Khonnamakitskiy, Indymskiy, Kochechumskiy series)
3. Marking cover of basalts of Kochechumskiy series
4. Tufas of lower Triassic (Korvunchanskiy series)
5. Intrusive dolerites of lower Triassic
6. Sedimentary (upper Permian) and volcanogenic - sedimentary (lower Triassic) rocks (Degalinskiy and Tutonchanskiy series)
7. Fault disorders interpreted from space and aerial photographs and partially confirmed by geological and geophysical data
8. elements of occurrence

basalt dikes. In this case the lens of molten impactites is covered by glacial deposits. It is important to note that both the magnetic /144 and the density anomalies are nonradical and cannot be related to

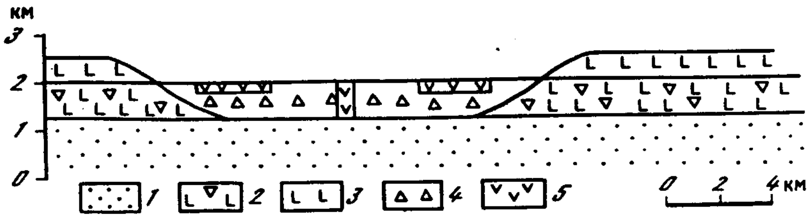

Figure 4. Density Model of Logancha Astrobleme
Key:
1. Argillaceous and carbonaceous shales, aleurolytes (Degalinskiy series, P_2), $\sigma = 2.5\ g/cm^3$
2. Tufogenic mass (T_1), $\sigma = 2.69\ g/cm^3$
3. Traprock (effusive) mass (T_1), $\sigma = 2.8\ g/cm^3$
4. Allogenic breccias of coptogenic complex of Logancha astrobleme, $\Delta\sigma = 0.13\ g/cm^3$
5. Molten impactites (?) of Logancha astrobleme, $\Delta\sigma = +0.5\ g/cm^3$

endogenous objects (intrusive, volcanic necks, etc.). The annular nature of the geophysical fields is also illustrated by the change in physical properties of the rocks (density (fig. 5a) and magnetic susceptibility (fig. 5,b)) defined in samples. The histograms show an increase in dispersion of the measured characteristics the closer to the center of the structure.

Field and laboratory methods of study revealed the following signs of impact metamorphism in target rocks of the Logancha astrobleme: destruction cones, deformation belts, planar elements and partial isotropization in the plagioclase.

Destruction zones were recorded in the basalt porphyrites within the central elevation. The orientation of 21 destruction cones extended in a northeast - southwest direction (azimuth of drop 48° and azimuth of rise 223° respectively) with mean inclination 25 - 35° was measured in bed outcrop. Fragments of the cone are known inthe deluvium and alluvium. The destruction cones are up to 20 - 30 cm high and have apex angle of 35 - 45°. Their surface is covered with characteristic grooves and swells (see photoplate 12, c, d)*. The pressure of the shock wave in which the destruction cones

* Translator's note: not included with this text.

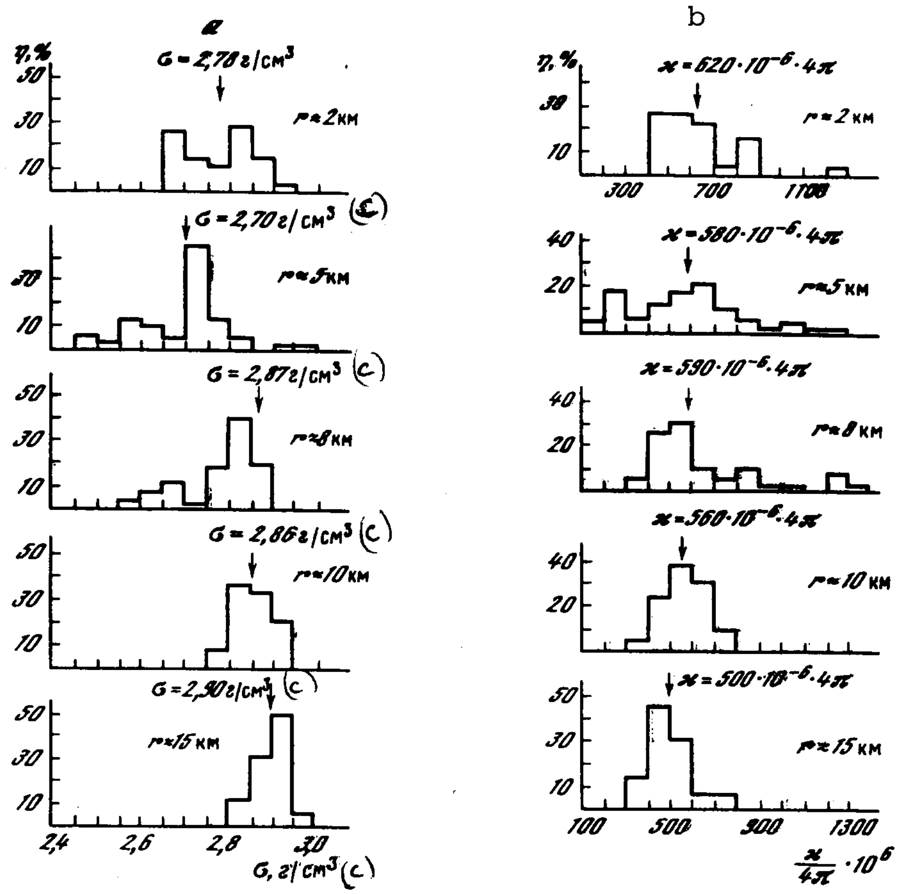

Figure 5. Dependence of Density (a) and Magnetic Susceptibility (b) of Rocks of the Foundation on Distance between the Site of Sample Taking and the Center of the Logancha Astrobleme (321 measurements)

Key:
c. g/cm^3

emerged in the Logancha structure was estimated as 2.0 - 5.0 GPa [Feldman et al., 1983].

Diaplect changes inthe plagioclase are represented by deformation belts, planar elements and partial isotropization. Only mosaic (block)extinction is noted in the pyroxenes.

The brief characteristics given above for the two traprock astroblemes, Lonar and Logancha, indicate that they differ in a /145 number of specific features from the impact structures on other targets [Bazilevskiy et al., 1983; Fel'dman et al, 1981]. These differences primarily include: 1) reduced height of the swell (as compared to the structures of similar size on other targets); 2) the small number or absence of molten impactites in the form of solid bodies;3) lower load in the crater center; 4) weak pronouncement in the gravitational field.

The main reason for these differences is apparently the target structure: alternation of layers (blocks) of varying competence. For Lonar, this is interstratification of basalts of varying degree of weathering, and in Logancha, in addition to interstratification of basalts and tufas, there is also occurrence of a "rigid" trap mass on "soft" carboniferous. This leads to a change in the correlations of the height of the swell and the diameter of the crater, decrease in loads in the rocks of the central elevation (because of the more rapid damping of the shock wave) and reduction of the density anomaly 4 - 5-fold (because the comparatively loose rocks are not loosened but compacted). On the other hand, increased porosity of the sedimentary rocks (or the weathering crust) determines the higher water saturation of the target, causing participation of large quantities of water vapor in the impact compression - relief cycle, which, in turn, results in dispersion of the melt and its ejection from the crater.

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16. Abstract

The paper briefly characterizes the two known terrestrial meteorite craters on traprock: (1) Lonar, India (diameter 1.8 km) and Logancha, USSR (diameter 20 km). The features these craters have in common are identified, and their differences from astroblemes on other types of targets are indicated. The probable reasons for these differences are discussed.

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